MODULAR FUEL INJECTOR AND METHOD OF ASSEMBLING THE MODULAR FUEL INJECTOR

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Background of the Invention

It is believed that examples of known fuel injection systems use an injector to dispense a quantity of fuel that is to be combusted in an internal combustion engine. It is also believed that the quantity of fuel that is dispensed is varied in accordance with a number of engine parameters such as engine speed, engine load, engine emissions, etc.

It is believed that examples of known electronic fuel injection systems monitor at least one of the engine parameters and electrically operate the injector to dispense the fuel. It is believed that examples of known injectors use electro-magnetic coils, piezoelectric elements, or magnetostrictive materials to actuate a valve.

It is believed that examples of known valves for injectors include a closure member that is movable with respect to a seat. Fuel flow through the injector is believed to be prohibited when the closure member sealingly contacts the seat, and fuel flow through the injector is believed to be permitted when the closure member is separated from the seat.

It is believed that examples of known injectors include a spring providing a force biasing the closure member toward the seat. It is also believed that this biasing force is adjustable in order to set the dynamic properties of the closure member movement with respect to the seat.

It is further believed that examples of known injectors include a filter for separating particles from the fuel flow, and include a seal at a connection of the injector to a fuel source.

It is believed that such examples of the known injectors have a number of disadvantages.

It is believed that examples of known injectors must be assembled entirely in an environment that is substantially free of contaminants. It is also believed that examples of known injectors can only be tested after final assembly has been completed.

Summary of the Invention

According to the present invention, a fuel injector can comprise a plurality of modules, each of which can be independently assembled and tested. According to one embodiment of the present invention, the modules can comprise a fluid handling subassembly and an electrical subassembly. These subassemblies can be subsequently assembled to provide a fuel injector according to the present invention.

The present invention provides a fuel injector for use with an internal combustion engine. The fuel injector comprises a valve group subassembly and a coil group subassembly. The valve group subassembly includes a tube assembly having a longitudinal axis extending between a first end and a second end, the tube assembly including an inlet tube having an inlet tube face; a seat secured at the second end of the tube assembly, the seat defining an opening. An armature assembly disposed within the tube assembly, the armature assembly having a closure member disposed at one end of the armature assembly and an armature portion disposed at the other end of the armature assembly, the armature assembly having an armature face; a member biasing the armature assembly toward the seat. A filter assembly disposed within the tube assembly; an adjusting tube disposed within the tube assembly proximate the second end; a non-magnetic shell extending axially along the axis and coupled at one end of the shell to the inlet tube. A valve body coupled to the other end of the non-magnetic shell. A lift setting device disposed within the valve body. A valve seat disposed within the valve body and contiguously engaging the closure member; and a first attaching portion. The coil group subassembly includes a housing, a bobbin disposed partially within the housing, the bobbin having at least one contact portion formed thereon; a solenoid coil operable to displace the armature assembly with respect to the seat, the solenoid coil being electrically coupled to the contact terminals. At least one pre-bent terminal being electrically coupled to the contact portion; at least one overmold; and a second attaching portion fixedly connected to the first attaching portion.

The present invention also provides for a method of assembling a fuel injector. The method comprises providing a valve group subassembly and a coil group subassembly, inserting the valve group subassembly into the coil group subassembly, aligning the valve group subassembly relative to the coil group subassembly and affixing the two subassemblies. The valve group subassembly includes a tube assembly having a longitudinal axis extending between a first end and a second end, the tube assembly including an inlet tube having an inlet tube face; a seat secured at the second end of the tube assembly, the seat defining an opening; an armature assembly disposed within the tube assembly, the armature assembly having a closure member disposed at one end of the armature assembly and an armature portion disposed at the other end of the armature assembly, the armature assembly having an armature face; a member biasing the armature assembly toward the seat; a filter assembly disposed within the tube assembly; an adjusting tube disposed within the tube assembly proximate the second end; a non-magnetic shell extending axially along the axis and coupled at one end of the shell to the inlet tube; a valve body coupled to the other end of the non-magnetic shell; a lift setting device disposed within the valve body; a valve seat disposed within the valve body and contiguously engaging the closure member; and a first attaching portion. The coil group subassembly includes a housing; a bobbin disposed partially within the housing, the bobbin having at least one contact portion formed thereon; a solenoid coil operable to displace the armature assembly with respect to the seat, the solenoid coil being electrically coupled to the contact terminals; at least one pre-bent terminal electrically coupled to the contact portion; and at least one overmold.

The present invention also provides yet another method of assembling a modular fuel injector. The method comprises providing a valve group subassembly and a coil group subassembly, inserting the valve group subassembly into the coil group subassembly, aligning the valve group subassembly relative to the coil group subassembly and affixing the two subassemblies. The valve group subassembly includes a tube assembly having a longitudinal axis extending between a first end and a second end, the tube assembly including an inlet tube having an inlet tube face; a seat secured at the second end of the tube assembly, the seat defining an opening; an armature assembly disposed

within the tube assembly, the armature assembly having a closure member disposed at one end of the armature assembly and an armature portion disposed at the other end of the armature assembly, the armature assembly having an armature face; a member biasing the armature assembly toward the seat; a filter assembly disposed within the tube assembly; an adjusting tube disposed within the tube assembly proximate the second end; a non-magnetic shell extending axially along the axis and coupled at one end of the shell to the inlet tube; a valve body coupled to the other end of the non-magnetic shell; a lift setting device disposed within the valve body; a valve seat disposed within the valve body and contiguously engaging the closure member; and a first attaching portion. The coil group subassembly includes a housing; a bobbin disposed partially within the housing, the bobbin having at least one contact portion formed thereon; a solenoid coil operable to displace the armature assembly with respect to the seat, the solenoid coil being electrically coupled to the contact terminals; at least one pre-bent terminal electrically coupled to the contact portion; and at least one overmold. The providing of the coil group or the power group further includes providing a clean room, fabricating the valve group in the clean room that comprises between 52 to 62 percent of a predetermined number of operations to assemble a ready-to-be shipped modular fuel injector, testing at least one of the valve group subassembly and coil group subassembly that comprises between 3 to 13 percent of the predetermined number of operations, performing welding operations on at least one of the valve group and coil group subassemblies that comprises between 3 to 8 percent of the predetermined number of operations, performing machine screw operations and machining operations on at least one of the valve group and the coil group subassemblies that comprise between 3 to 9 percent of the predetermined number of operations. At least one of the providing of the coil group subassembly and the assembling of the valve group and the coil group subassemblies can be performed, either inside or outside of the clean room, that comprises between 12 to 22 percent of the predetermined number of operations.

The present invention also provides method of manufacturing a fuel injector by providing a clean room, fabricating a fuel tube assembly, an armature assembly and fabricating a seat assembly in the clean room, assembling a fuel group by inserting an adjusting tube into the fuel tube assembly; inserting a biasing element into the fuel tube

assembly; inserting the armature assembly into the fuel tube assembly; connecting the seat assembly to the fuel tube assembly; and inserting the fuel group into a power group outside the clean room.

The present invention further provides a method of assembling a fuel injector by providing a clean room, fabricating a fuel tube assembly, an armature assembly and a seat assembly in the clean room; assembling the fuel group by inserting an adjusting tube into the fuel tube assembly; inserting a biasing element into the fuel tube assembly; inserting the armature assembly into the fuel tube assembly; and connecting the seat assembly to the fuel tube assembly.

The present invention additionally provides for a method of manufacturing a modular fuel injector. The method comprises providing a clean room, manufacturing a sealed fuel injector unit via a predetermined number of operations by fabricating a fuel group in the clean room; testing the fuel injector including testing the fuel group and a power group; performing welding operations on at least one of the fuel group and power group; machining and performing screw machine operations on at least one of the fuel group and power group; and assembling the fuel group with a power group outside the clean room into a sealed modular fuel injector unit. Each of the fabricating, testing, performing, machining and assembling operation comprises, respectively, a specified range of the predetermined number of operations.

The present invention provides yet another method of assembling a modular fuel injector. The method comprises providing a clean room, assembling a ready-to-deliver modular fuel injector unit by a predetermined number of assembling operations. The assembling operations include fabricating a fuel group in the clean room that comprises between 52 to 62 percent of the predetermined number of operations; testing the fuel injector including testing the fuel group and a power group that comprises between 3 to 13 percent of the predetermined number of operations; performing welding operations on at least one of the fuel group and power group that comprise between 3 to 8 percent of the predetermined number of operations; machining and performing machine screw operations on at least one of the fuel group and power group that comprise between 3 to 9 percent of the predetermined number of operations; and assembling the fuel group with a power

group outside the clean room into a ready-to-deliver modular fuel injector unit that comprises between 12 to 22 percent of the predetermined number of operations.

The present invention further provides a method of setting armature lift in a fuel injector. The method comprises providing a tube assembly, providing a seat assembly having a seating surface, connecting the seat assembly to the second valve body end, and adjusting the distance between the first tube assembly end and the seating surface. The tube assembly includes an inlet tube assembly having a first tube assembly end; a non-magnetic shell having a first shell end and a second shell end, the first shell end being connected to the first tube assembly end; and a valve body having a first valve body end and a second valve body end, the first valve body end being connected to the second shell end.

The present invention additionally provides a method of connecting a fuel group to a power group. The method includes providing a fuel tube assembly having a longitudinal axis extending therethrough; installing an orifice plate on the fuel tube assembly, rotating the power group relative to the fuel group such that the at least one opening is disposed a predetermined angle from the power connector relative to the longitudinal axis; installing the fuel group in a power group; and fixedly connecting the fuel group to the power group. The orifice plate having at least one opening disposed away from the longitudinal axis. The power group includes a generally axially extending dielectric overmold and a power connector extending generally radially therefrom.

The present invention further provides a method of connecting a fuel group to a power group in a fuel injector. The method includes manufacturing a fuel group. The manufacturing includes providing a fuel tube assembly having a longitudinal axis extending therethrough; installing an orifice plate on the fuel tube assembly, the orifice plate having at least one opening disposed away from the longitudinal axis. The method further comprises providing a power group having a generally axially extending dielectric overmold and a power connector extending generally radially therefrom; rotating the power group relative to the fuel group such that the at least one opening is disposed a predetermined angle from the power connector relative to the longitudinal axis. After the

power group is rotated, installing the fuel group in the power group, and fixedly connecting the fuel group to the power group.

Brief Description of the Drawings

The accompanying drawings, which are incorporated herein and constitute part of this specification, illustrate an embodiment of the invention, and, together with the general description given above and the detailed description given below, serve to explain features of the invention.

Figure 1 is a cross-sectional view of a fuel injector according to the present invention.

Figure 1A is a cross-sectional view of a variation on the filter assembly of the fuel injector according to the present invention.

Figure 2 is a cross-sectional view of a fluid handling subassembly of the fuel injector shown in Figure 1.

Figure 2A is a cross-sectional view of a variation of the fuel filter in the fluid handling subassembly of the fuel injector shown in Figure 2.

Figures 2B-2D are cross-sectional views of views of various inlet tube assemblies usable in the fuel injector.

Figures 2E and 2F are close-up views of the surface treatments for the impact surfaces of the electromagnetic actuator of the fuel injector.

Figures 2G-2I are cross-sectional views of various armature assemblies usable with the fuel injector.

Figures 2J-2L are cross-sectional views of various valve closure members usable with the fuel injector.

Figure 2M illustrates one preferred embodiment to retain the orifice plate and the sealing member at an outlet end of the fuel injector.

Figures 2N and 2O are exploded views of how an injector lift can be set for the fuel injector.

Figure 3 is a cross-sectional view of an electrical subassembly of the fuel injector shown in Figure 1.

Figure 3A is a cross-sectional view of the two-piece overmold instead of the one-piece overmold of the electrical subassembly of Figure 3.

Figure 3B is an exploded view of the electrical subassembly of the fuel injector of Figure 1.

Figure 4 is an isometric view that illustrates assembling the fluid handling and electrical subassemblies that are shown in Figures 2 and 3, respectively.

Figures 4A and 4B are close-up views of the high efficiency magnetic assembly as utilized in the fuel injector.

Figure 5 is a flow chart of the method of assembling the modular fuel injector according to the present invention.

Figures 5A-5F are detailed illustrations of the method summarized in Figure 5.

Detailed Description of the Preferred Embodiment

Referring to Figures 1-4, a solenoid actuated fuel injector 100 dispenses a quantity of fuel that is to be combusted in an internal combustion engine (not shown). The fuel injector 100 extends along a longitudinal axis between a first injector end 238 and a second injector end 239, and includes a valve group subassembly 200 and a power group subassembly 300. The valve group subassembly 200 performs fluid handling functions, e.g., defining a fuel flow path and prohibiting fuel flow through the injector 100. The power group subassembly 300 performs electrical functions, e.g., converting electrical signals to a driving force for permitting fuel flow through the injector 100.

Referring to Figures 1 and 2, the valve group subassembly 200 comprises a tube assembly extending along the longitudinal axis A-A between a first tube assembly end 200A and a second tube assembly end 200B. The tube assembly includes at least an inlet tube, a non-magnetic shell 230, and a valve body. The inlet tube has a first inlet tube end proximate to the first tube assembly end 200A. A second inlet tube end of the inlet tube is connected to a first shell end of the non-magnetic shell 230. A second shell end of the non-magnetic shell 230 is connected to a first valve body end of the valve body. A second valve body end of the valve body 240 is disposed proximate to the second tube assembly end 200B. The inlet tube can be formed by a deep drawing process or by a rolling

operation. A pole piece can be integrally formed at the second inlet tube end of the inlet tube or, as shown, a separate pole piece 220 can be connected to a partial inlet tube and connected to the first shell end of the non-magnetic shell 230. The non-magnetic shell 230 can comprise non-magnetic stainless steel, e.g., 300 series stainless steels, or other materials that have similar structural and magnetic properties.

As shown in Figure 2, inlet tube 210 is attached to pole piece 220 by means of welds. Formed into the outer surface of pole piece 220 are shoulders 222A, which, in conjunction with shoulders 222B of the coil subassembly, act as positive mounting stops when the injector is assembled. As shown in Figures 2C and 2D, the length of pole piece is fixed whereas the length of inlet tube can vary according to operating requirements. By forming inlet tube 210 separately from pole piece 220, different length injectors can be manufactured by using different inlet tube lengths during the assembly process. Inlet tube 220 can be flared at the inlet end to retain the O-ring 290.

Referring again to Figure 2, the inlet tube 210 can be attached to the pole piece 220 at an inner circumferential surface of the pole piece 220. Alternatively, as shown in Figure 2B, an integral inlet tube and pole piece assembly 211 can be attached to the inner circumferential surface of the non-magnetic shell 230.

An armature assembly 260 is disposed in the tube assembly. The armature assembly 260 includes a first armature assembly end having a ferro-magnetic or armature portion 262 and a second armature assembly end having a sealing portion. The armature assembly 260 is disposed in the tube assembly such that the magnetic portion, or "armature," 262 confronts the pole piece 220. The sealing portion can include a closure member 264, e.g., a spherical valve element, that is moveable with respect to the seat 250 and its sealing surface 252. The closure member 264 is movable between a closed configuration, as shown in Figures 1 and 2, and an open configuration (not shown). In the closed configuration, the closure member 264 contiguously engages the sealing surface 252 to prevent fluid flow through the opening. In the open configuration, the closure member 264 is spaced from the seat 250 to permit fluid flow through the opening. The armature assembly 260 may also include a separate intermediate portion 266 connecting the ferro-magnetic or armature portion 262 to the closure member 264. The intermediate

portion or armature tube 266 can be fabricated by various techniques, for example, a plate can be rolled and its seams welded or a blank can be deep-drawn to form a seamless tube. The intermediate portion 266 is preferable due to its ability to reduce magnetic flux leakage from the magnetic circuit of the fuel injector 100. This ability arises from the fact that the intermediate portion or armature tube 266 can be non-magnetic, thereby magnetically decoupling the magnetic portion or armature 262 from the ferro-magnetic closure member 264. Because the ferro-magnetic closure member is decoupled from the ferro-magnetic or armature 262, flux leakage is reduced, thereby improving the efficiency of the magnetic circuit.

Surface treatments can be applied to at least one of the end portions 221 and 261 to improve the armature's response, reduce wear on the impact surfaces and variations in the working air gap between the respective end portions 221 and 261. The surface treatments can include coating, plating or case-hardening. Coatings or platings can include, but are not limited to, hard chromium plating, nickel plating or keronite coating. Case hardening on the other hand, can include, but are not limited to, nitriding, carburizing, carbo-nitriding, cyaniding, heat, flame, spark or induction hardening.

The surface treatments will typically form at least one layer of wear-resistant materials 261A or 221A on the respective end portions. This layers, however, tend to be inherently thicker wherever there is a sharp edge, such as between junction between the circumference and the radial end face of either portions. Moreover, this thickening effect results in uneven contact surfaces at the radially outer edge of the end portions. However, by forming the wear-resistant layers on at least one of the end portions 221 and 261, where at least one end portion has a surface 263 generally oblique to longitudinal axis A-A, both end portions are now substantially in mating contact with respect to each other.

As shown in Figure 2E, the end portions 221 and 261 are generally symmetrical about the longitudinal axis A-A. As further shown in Figure 2F, the surface 263 of at least one of the end portions can be of a general conic, frustoconical, spheroidal or a surface generally oblique with respect to the axis A-A.

Since the surface treatments may affect the physical and magnetic properties of the ferromagnetic portion of the armature assembly 260 or the pole piece 220, a suitable

material, e.g., a mask, a coating or a protective cover, surrounds areas other than the respective end portions 221 and 261 during the surface treatments. Upon completion of the surface treatments, the material is removed, thereby leaving the previously masked areas unaffected by the surface treatments.

Fuel flow through the armature assembly 260 can be provided by at least one axially extending through-bore 267 and at least one apertures 268 through a wall of the armature assembly 260. The apertures 268, which can be of any shape, are preferably non-circular, e.g., axially elongated, to facilitate the passage of gas bubbles. For example, in the case of a separate intermediate portion 266 that is formed by rolling a sheet substantially into a tube, the apertures 268 can be an axially extending slit defined between non-abutting edges of the rolled sheet. However, the apertures 268, in addition to the slit, would preferably include openings extending through the sheet. The apertures 268 provide fluid communication between the at least one through-bore 267 and the interior of the valve body. Thus, in the open configuration, fuel can be communicated from the through-bore 267, through the apertures 268 and the interior of the valve body, around the closure member, and through the opening into the engine (not shown).

To permit the use of extended tip injectors, Figure 2G shows a three-piece armature 260 comprising the armature tube 266, elongated openings 268 and the closure member 264. One example of an extended tip three-piece armature is shown as armature assembly 260A in Fig. 2H. The extended tip armature assembly 260A includes elongated apertures 269 to facilitate the passage of trapped fuel vapor. As a further alternative, a two-piece armature 260B, shown here in Fig. 2I, can be utilized with the present invention. Although both the three-piece and the two-piece armature assemblies are interchangeable, the three-piece armature assembly 266 or 266A is preferable due to its ability to reduce magnetic flux leakage from the magnetic circuit of the fuel injector 100 according to the present invention. This ability arises from the fact that the armature tube 266 or 266A can be non-magnetic, thereby magnetically decoupling the magnetic portion or armature 262 from the ferro-magnetic closure member 264. Because the ferro-magnetic closure member is decoupled from the ferro-magnetic or armature portion 262, flux leakage is reduced, thereby improving the efficiency of the magnetic circuit. Furthermore, the three-piece

armature assembly can be fabricated with fewer machining processes as compared to the two-piece armature assembly. It should be noted that the armature tube 266 or 266A of the three-piece armature assembly can be fabricated by various techniques, for example, a plate can be rolled and its seams welded or a blank can be deep-drawn to form a seamless tube.

The elongated openings 269 and apertures 268 in the three-piece extended tip armature 260A serve two related purposes. First, the elongated openings 269 and apertures 268 allow fuel to flow out of the armature tube 266A. Second, elongated openings 269 allows hot fuel vapor in the armature tube 266A to vent into the valve body 240 instead of being trapped in the armature tube 266A, and also allows pressurized liquid fuel to displace any remaining fuel vapor trapped therein during a hot start condition.

A seat 250 is secured at the second end of the tube assembly. The seat 250 defines an opening centered on the axis A-A and through which fuel can flow into the internal combustion engine (not shown). The seat 250 includes a sealing surface 252 surrounding the opening. The sealing surface, which faces the interior of the valve body 240, can be frustoconical or concave in shape, and can have a finished surface. An orifice disk 254 can be used in connection with the seat 250 to provide at least one precisely sized and oriented orifice 254A in order to obtain a particular fuel spray pattern. The precisely sized and oriented orifice 254A can be disposed on the center axis of the orifice plate 254 as shown in Figure 2N or, preferably, an orifice 254B can disposed off-axis, shown in Figure 2O, and oriented in any desirable angular configuration relative to one or more reference points on the fuel injector 100. It should be noted here that both the valve seat 250 and orifice plate are fixedly attached to the valve body by known conventional attachment techniques, including, for example, laser welding, crimping, and friction welding or conventional welding. Alternatively, a cap-shaped retainer 258 as shown in Figure 2M can retain the orifice plate 254 on the valve body 240.

As shown in Figure 2J, the orifice plate 254 is attached to the valve seat 250, which valve seat 250 is attached to the valve body 240. To ensure a positive seal, closure member 264 is attached to intermediate portion 266 by welds and is biased by resilient member 270 towards a closed position. To achieve different spray patterns or to ensure a large volume

of fuel injected relative to a low injector lift height, it is contemplated that the spherical closure member 264 be in the form of a flat-faced ball, shown enlarged in detail in Figures 2K and 2L. Welds 261 can be internally formed between the junction of the intermediate portion 266 and the closure member 264 to the intermediate portion 266, respectively. Valve seat 250 can be attached to valve body 240 in two different ways. As shown in Fig. 2K, valve seat 250 may simply be floatingly mounted between valve body 240 and orifice plate 254 with an O-ring 251 to prevent fuel leakage around valve seat 250. Here, the orifice plate 254 can be retained by crimps 240A that can be formed on the valve body 240. Alternatively, valve seat 250 may simply be affixed by at least a weld 251A to valve body 240 as shown in Fig. 2L while the orifice plate 254 can be welded to the seat 250.

In the case of a spherical valve element providing the closure member, the spherical valve element can be connected to the armature assembly 260 at a diameter that is less than the diameter of the spherical valve element. Such a connection would be on side of the spherical valve element that is opposite contiguous contact with the seat 250. A lower armature guide can be disposed in the tube assembly, proximate the seat 250, and would slidingly engage the diameter of the spherical valve element. The lower armature guide can facilitate alignment of the armature assembly 260 along the axis A-A.

Referring back to the retainer 258, shown enlarged in Figure 2M, the retainer includes finger-like locking portions 259B allowing the retainer 258 to be snap-fitted on a complementarily grooved portion 259A of the valve body 240. Retainer 258 is further retained on the valve body 240 by resilient locking, finger-like portions 259, which are received, by complementary grooved portions 259A on the valve body 240. To retain the orifice disk 254 flush against the valve seat 250, a dimpled or recessed portion 259C is formed on the radial face of the retainer 258 to receive the orifice disk 254. To ensure that the retainer 258 is imbued with sufficient resiliency, the thickness of the retainer 258 should be at most one-half the thickness of the valve body. A flared-portion 259D of the retainer 258 also supports the sealing o-ring 290. The use of resilient retainer 258 obviates the need for welding the orifice disk 254 to the valve seat 250 while also functioning as an o-ring support.

A resilient member 270 is disposed in the tube assembly and biases the armature assembly 260 toward the seat 250. A filter assembly 282 comprising a filter 284A and an integral retaining portion 283 is also disposed in the tube assembly. The filter assembly 282 includes a first end and a second end. The filter 284A is disposed at one end of the filter assembly 282 and also located proximate to the first end of the tube assembly and apart from the resilient member 270 while the adjusting tube 281 is disposed generally proximate to the second end of the tube assembly. The adjusting tube 281 engages the resilient member 270 and adjusts the biasing force of the member with respect to the tube assembly. In particular, the adjusting tube 281 provides a reaction member against which the resilient member 270 reacts in order to close the injector valve 100 when the power group subassembly 300 is de-energized. The position of the adjusting tube 281 can be retained with respect to the inlet tube 210 by an interference fit between an outer surface of the adjusting tube 281 and an inner surface of the tube assembly. Thus, the position of the adjusting tube 281 with respect to the inlet tube 210 can be used to set a predetermined dynamic characteristic of the armature assembly 260.

The filter assembly 282 includes a cup-shaped filtering element 284A and an integral-retaining portion 283 for positioning an O-ring 290 proximate the first end of the tube assembly. The O-ring 290 circumscribes the first end of the tube assembly and provides a seal at a connection of the injector 100 to a fuel source (not shown). The retaining portion 283 retains the O-ring 290 and the filter element with respect to the tube assembly.

Two variations on the fuel filter of Figure 1 are shown in Figures 1A and 2A. In Figure 1A, a fuel filter assembly 282' with filter 285 is attached to the adjusting tube 280'. Likewise, in Figure 2A, the filter assembly 282" includes an inverted-cup filtering element 284B attached to an adjusting tube 280". Similar to adjusting tube 281 described above, the adjusting tube 280' or 280" of the respective fuel filter assembly 282' or 282" engages the resilient member 270 and adjusts the biasing force of the member with respect to the tube assembly. In particular, the adjusting tube 280' or 280" provides a reaction member against which the resilient member 270 reacts in order to close the injector valve 100 when the power group subassembly 300 is de-energized. The position of the adjusting tube 280'

or 280" can be retained with respect to the inlet tube 210 by an interference fit between an outer surface of the adjusting tube 280' or 280" and an inner surface of the tube assembly.

The valve group subassembly 200 can be assembled as follows. The non-magnetic shell 230 is connected to the inlet tube 210 and to the valve body. The adjusting tube 280A or the filter assembly 282' or 282" is inserted along the axis A-A from the first end 200A of the tube assembly. Next, the resilient member 270 and the armature assembly 260 (which was previously assembled) are inserted along the axis A-A from the injector end 239 of the valve body 240. The adjusting tube 280A, the filter assembly 282' or 282" can be inserted into the inlet tube 210 to a predetermined distance so as to permit the adjusting tube 280A, 280B or 280C to preload the resilient member 270. Positioning of the filter assembly 282, and hence the adjusting tube 280B or 280C with respect to the inlet tube 210 can be used to adjust the dynamic properties of the resilient member 270, e.g., so as to ensure that the armature assembly 260 does not float or bounce during injection pulses. The seat 250 and orifice disk 254 are then inserted along the axis A-A from the second valve body end of the valve body. The seat 250 and orifice disk 254 can be fixedly attached to one another or to the valve body by known attachment techniques such as laser welding, crimping, friction welding, conventional welding, etc.

Referring to Figures 1 and 3, the power group subassembly 300 comprises an electromagnetic coil 310, at least one terminal 320, a housing 330, and an overmold 340. The electromagnetic coil 310 comprises a wire 312 that that can be wound on a bobbin 314 and electrically connected to electrical contacts on the bobbin 314. When energized, the coil generates magnetic flux that moves the armature assembly 260 toward the open configuration, thereby allowing the fuel to flow through the opening. De-energizing the electromagnetic coil 310 allows the resilient member 270 to return the armature assembly 260 to the closed configuration, thereby shutting off the fuel flow. The housing, which provides a return path for the magnetic flux, generally comprises a ferro-magnetic cylinder 332 surrounding the electromagnetic coil 310 and a flux washer 334 extending from the cylinder toward the axis A-A. The washer 334 can be integrally formed with or separately attached to the cylinder. The housing 330 can include holes, slots, or other features to break-up eddy currents that can occur when the coil is energized.

The overmold 340 maintains the relative orientation and position of the electromagnetic coil 310, the at least one terminal (two are used in the illustrated example), and the housing. The overmold 340 includes an electrical harness connector 321 portion in which a portion of the terminal 320 is exposed. The terminal 320 and the electrical harness connector 321 portion can engage a mating connector, e.g., part of a vehicle wiring harness (not shown), to facilitate connecting the injector 100 to an electrical power supply (not shown) for energizing the electromagnetic coil 310.

According to a preferred embodiment, the magnetic flux generated by the electromagnetic coil 310 flows in a circuit that comprises, the pole piece 220, the armature assembly 260, the valve body 240, the housing 330, and the flux washer 334. As seen in Figures 4A and 4B, the magnetic flux moves across a parasitic airgap between the homogeneous material of the magnetic portion or armature 262 and the valve body 240 into the armature assembly 260 and across the working air gap towards the pole piece 220, thereby lifting the closure member 264 off the seat 250. As can further be seen in Figure 4B, the width "a" of the impact surface of pole piece 220 is greater than the width "b" of the cross-section of the impact surface of magnetic portion or armature 262. The smaller cross-sectional area "b" allows the ferro-magnetic portion 262 of the armature assembly 260 to be lighter, and at the same time, causes the magnetic flux saturation point to be formed near the working air gap between the pole piece 220 and the ferro-magnetic portion 262, rather than within the pole piece 220. Furthermore, since the armature 262 is partly within the interior of the electromagnetic coil 310, the magnetic flux is denser, leading to a more efficient electromagnetic coil. Finally, because the ferro-magnetic closure member 264 is magnetically decoupled from the ferro-magnetic or armature portion 262 via the armature tube 266, flux leakage of the magnetic circuit is reduced, thereby improving the efficiency of the electromagnetic coil 310.

The coil group subassembly 300 can be constructed as follows. A plastic bobbin 314 can be molded with at least one electrical contacts 322. The wire 312 for the electromagnetic coil 310 is wound around the plastic bobbin 314 and connected to the electrical contacts 322. The housing 330 is then placed over the electromagnetic coil 310 and bobbin 314. A terminal 320, which is pre-bent to a proper shape, is then electrically

connected to each electrical contact 322. An overmold 340 is then formed to maintain the relative assembly of the coil/bobbin unit, housing 330, and terminal 320. The overmold 340 also provides a structural case for the injector and provides predetermined electrical and thermal insulating properties. A separate collar can be connected, e.g., by bonding, and can provide an application specific characteristic such as an orientation feature or an identification feature for the injector 100. Thus, the overmold 340 provides a universal arrangement that can be modified with the addition of a suitable collar. To reduce manufacturing and inventory costs, the coil/bobbin unit can be the same for different applications. As such, the terminal 320 and overmold 340 (or collar, if used) can be varied in size and shape to suit particular tube assembly lengths, mounting configurations, electrical connectors, etc.

Alternatively, as shown in Fig. 3A, a two-piece overmold allows for a first overmold 341 that is application specific while the second overmold 342 can be for all applications. The first overmold 341 is bonded to a second overmold 342, allowing both to act as electrical and thermal insulators for the injector. Additionally, a portion of the housing 330 can extend axially beyond an end of the overmold 340 to allow the injector to accommodate different length injector tips. The extended portion also can be formed with a flange to retain an O-ring.

As is particularly shown in Figures 1 and 4, the valve group subassembly 200 can be inserted into the coil group subassembly 300. Thus, the injector 100 is made of two modular subassemblies that can be assembled and tested separately, and then connected together to form the injector 100. The valve group subassembly 200 and the coil group subassembly 300 can be fixedly attached by adhesive, welding, or another equivalent attachment process. According to a preferred embodiment, a hole 360 through the overmold 340 exposes the housing 330 and provides access for laser welding the housing 330 to the valve body. The filter and the retainer, which may be an integral unit, can be connected to the first tube assembly end 200A of the tube unit. The O-rings can be mounted at the respective first and second injector ends.

The first injector end 238 can be coupled to the fuel supply of an internal combustion engine (not shown). The O-ring 290 can be used to seal the first injector end

238 to the fuel supply so that fuel from a fuel rail (not shown) is supplied to the tube assembly, with the O-ring 290 making a fluid tight seal, at the connection between the injector 100 and the fuel rail (not shown).

In operation, the electromagnetic coil 310 is energized, thereby generating magnetic flux in the magnetic circuit. The magnetic flux moves armature assembly 260 (along the axis A-A, according to a preferred embodiment) towards the integral pole piece 220, i.e., closing the working air gap. This movement of the armature assembly 260 separates the closure member 264 from the seat 250 and allows fuel to flow from the fuel rail (not shown), through the inlet tube 210, the through-bore 267, the apertures 268 and the valve body, between the seat 250 and the closure member, through the opening, and finally through the orifice disk 254 into the internal combustion engine (not shown). When the electromagnetic coil 310 is de-energized, the armature assembly 260 is moved by the bias of the resilient member 270 to contiguously engage the closure member 265 with the seat 250, and thereby prevent fuel flow through the injector 100.

Referring to Figure 5, a preferred assembly process can be as follows:

1. A pre-assembled valve body and non-magnetic sleeve is located with the valve body oriented up.
2. A screen retainer, e.g., a lift sleeve, is loaded into the valve body/non-magnetic sleeve assembly.
3. A lower screen can be loaded into the valve body/non-magnetic sleeve assembly.
4. A pre-assembled seat and guide assembly is loaded into the valve body/non-magnetic sleeve assembly.
5. The seat/guide assembly is pressed to a desired position within the valve body/non-magnetic sleeve assembly.
6. The valve body is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the seat.
7. A first leak test is performed on the valve body/non-magnetic sleeve assembly. This test can be performed pneumatically.

8. The valve body/non-magnetic sleeve assembly is inverted so that the non-magnetic sleeve is oriented up.
9. An armature assembly is loaded into the valve body/non-magnetic sleeve assembly.
10. A pole piece is loaded into the valve body/non-magnetic sleeve assembly and pressed to a pre-lift position.
11. Dynamically, e.g., pneumatically, purge valve body/non-magnetic sleeve assembly.
12. Set lift.
13. The non-magnetic sleeve is welded, e.g., with a tack weld, to the pole piece.
14. The non-magnetic sleeve is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the pole piece.
15. Verify lift
16. A spring is loaded into the valve body/non-magnetic sleeve assembly.
17. A filter/adjusting tube is loaded into the valve body/non-magnetic sleeve assembly and pressed to a pre-cal position.
18. An inlet tube is connected to the valve body/non-magnetic sleeve assembly to generally establish the fuel group subassembly.
19. Axially press the fuel group subassembly to the desired over-all length.
20. The inlet tube is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the pole piece.
21. A second leak test is performed on the fuel group subassembly. This test can be performed pneumatically.
22. The fuel group subassembly is inverted so that the seat is oriented up.
23. An orifice is punched and loaded on the seat.

24. The orifice is welded, e.g., by a continuous wave laser forming a hermetic lap seal, to the seat.

25. The rotational orientation of the fuel group subassembly/orifice can be established with a "look/orient/look" procedure using reference points on the valve body subassembly and the coil group subassembly. For example, a computer equipped with machine vision can locate a reference point on the orifice plate of the fuel group and a reference point on the fuel group subassembly. The computer then rotate at least one or both of the fuel group and the power group as a function of a calculated angular difference between the two reference points. Subsequently, the two subassemblies are inserted or press-fitted into each other.

26. The fuel group subassembly is inserted into the (pre-assembled) power group subassembly.

27. The power group subassembly is pressed to a desired axial position with respect to the fuel group subassembly.

28. The rotational orientation of the fuel group subassembly/orifice/power group subassembly can be verified.

29. The power group subassembly can be laser marked with information such as part number, serial number, performance data, a logo, etc.

30. Perform a high-potential electrical test.

31. The housing of the power group subassembly is tack welded to the valve body.

32. A lower O-ring can be installed. Alternatively, this lower O-ring can be installed as a post test operation.

33. An upper O-ring is installed.

34. Invert the fully assembled fuel injector.

35. Transfer the injector to a test rig.

To set the lift, i.e., ensure the proper injector lift distance, there are at least four different techniques that can be utilized. According to a first technique, a crush ring or a washer that is inserted into the valve body 240 between the lower guide 257 and the valve body 240 can be deformed. According to a second technique, the relative axial position of the valve body 240 and the non-magnetic shell 230 can be adjusted before the two parts are affixed together. According to a third technique, the relative axial position of the non-magnetic shell 230 and the pole piece 220 can be adjusted before the two parts are affixed together. And according to a fourth technique, a lift sleeve 255 can be displaced axially within the valve body 240. If the lift sleeve technique is used, the position of the lift sleeve can be adjusted by moving the lift sleeve axially. The lift distance can be measured with a test probe. Once the lift is correct, the sleeve is welded to the valve body 240, e.g., by laser welding. Next, the valve body 240 is attached to the inlet tube 210 assembly by a weld, preferably a laser weld. The assembled fuel group subassembly 200 is then tested, e.g., for leakage.

As is shown in Figure 5, the lift set procedure may not be able to progress at the same rate as the other procedures. Thus, a single production line can be split into a plurality (two are shown) of parallel lift setting stations, which can thereafter be recombined back into a single production line.

The preparation of the power group sub-assembly, which can include (a) the housing 330, (b) the bobbin assembly including the terminals 320, (c) the flux washer 334, and (d) the overmold 340, can be performed separately from the fuel group subassembly.

According to a preferred embodiment, wire 312 is wound onto a pre-formed bobbin 314 having electrical connector portions 322. The bobbin assembly is inserted into a pre-formed housing 330, shown here in Figure 3B. To provide a return path for the magnetic flux between the pole piece 220 and the housing 330, flux washer 334 is mounted on the bobbin assembly. A pre-bent terminal 320 having axially extending connector portions 324 are coupled to the electrical contact portions 322 and brazed, soldered welded, or, preferably, resistance welded. The partially assembled power group assembly is now placed into a mold (not shown). By virtue of its pre-bent shape, the terminals 320 will be positioned in the proper orientation with the harness connector 321 when a polymer is

poured or injected into the mold. Alternatively, two separate molds (not shown) can be used to form a two-piece overmold as described with respect to Figure 3A. The assembled power group subassembly 300 can be mounted on a test stand to determine the solenoid's pull force, coil resistance and the drop in voltage as the solenoid is saturated.

The inserting of the fuel group subassembly 200 into the power group subassembly 300 operation can involve setting the relative rotational orientation of fuel group subassembly 200 with respect to the power group subassembly 300. According to the preferred embodiments, the fuel group and the power group subassemblies can be rotated such that the included angle between the reference point(s) on the orifice plate 254 (including opening(s) thereon) and a reference point on the injector harness connector 321 are within a predetermined angle. The relative orientation can be set using robotic cameras or computerized imaging devices to look at respective predetermined reference points on the subassemblies, calculate the angular rotation necessary for alignment, orientating the subassemblies and then checking with another look and so on until the subassemblies are properly orientated. Once the desired orientation is achieved, the subassemblies are inserted together. The inserting operation can be accomplished by one of two methods: "top-down" or "bottom-up." According to the former, the power group subassembly 300 is slid downward from the top of the fuel group subassembly 200, and according to the latter, the power group subassembly 300 is slid upward from the bottom of the fuel group subassembly 200. In situations where the inlet tube 210 assembly includes a flared first end, bottom-up method is required. Also in these situations, the O-ring 290 that is retained by the flared first end can be positioned around the power group subassembly 300 prior to sliding the fuel group subassembly 200 into the power group subassembly 300. After inserting the fuel group subassembly 200 into the power group subassembly 300, these two subassemblies are affixed together, e.g., by welding, such as laser welding. According to a preferred embodiment, the overmold 340 includes an opening 360 that exposes a portion of the housing 330. This opening 360 provides access for a welding implement to weld the housing 330 with respect to the valve body 240. Of course, other methods or affixing the subassemblies with respect to one another can be used. Finally, the O-ring 290 at either end of the fuel injector can be installed.

To ensure that particulates from the manufacturing environment will not contaminate the fuel group subassembly, the process of fabricating the fuel group subassembly is preferably performed within a "clean room." "Clean room" here means that the manufacturing environment is provided with an air filtration system that will ensure that the particulates and environmental contaminants are continually removed from the clean room.

It is believed that for cost-effectiveness in manufacturing, the number of clean room operations can constitute, inclusively, between 45 - 55% of the total manufacturing operations while testing processes can constitute, inclusively, between 3% and 8% of the total manufacturing operations. Likewise, the welding and screw machining operations can constitute, inclusively, between 3% and 9% of the total operations. The number operations prior to a sealed modular fuel injector unit can constitute, inclusively, between 12% and 22% of the total manufacturing processes. Of course, the operations performed prior to a sealed fuel injector unit can be done either inside or outside the clean room, depending on the actual manufacturing environment.

As an example, in a preferred embodiment, there are approximately forty-nine (49) clean room processes, seven (7) test processes, three (3) subassembly processes outside of the clean room, five (5) welding processes, one (1) machining or grinding processes, and five (5) screw machine processes that result in a sealed, or ready to be shipped, modular fuel injector unit. The total number of manufacturing operations or processes can vary depending on variables such as, for example, whether the armature assembly 260 is pre-assembled or of a one-piece construction, the lower guide and the seat being integrally formed or of separate constructions, the parts being fully finished or unfinished, the fuel or power group being provided by a third party contractor(s) or subconstractor(s), or where any portion (or portions) of the assembling processes or operations being performed by a third party assembler, either on-site or off-site, etc. These exemplary variables and other variables controlling the actual number of the predetermined number of operations, the various proportions of the clean room operations, testing, welding, screw machine, grinding, machining, surface treatment and processes outside a clean room relative to the

predetermined number of operations will be known to those skilled in the art, and are within the scope of the present invention.

The method of assembly of the preferred embodiments, and the preferred embodiments themselves, are believed to provide manufacturing advantages and benefits. For example, because of the modular arrangement only the valve group subassembly is required to be assembled in a "clean" room environment. The power group subassembly 300 can be separately assembled outside such an environment, thereby reducing manufacturing costs. Also, the modularity of the subassemblies permits separate pre-assembly testing of the valve and the coil assemblies. Since only those individual subassemblies that test unacceptable are discarded, as opposed to discarding fully assembled injectors, manufacturing costs are reduced. Further, the use of universal components (e.g., the coil/bobbin unit, non-magnetic shell 230, seat 250, closure member 265, filter/retainer assembly 282' or 282", etc.) enables inventory costs to be reduced and permits a "just-in-time" assembly of application specific injectors. Only those components that need to vary for a particular application, e.g., the terminal 320 and inlet tube 210 need to be separately stocked. Another advantage is that by locating the working air gap, i.e., between the armature assembly 260 and the pole piece 220, within the electromagnetic coil 310, the number of windings can be reduced. In addition to cost savings in the amount of wire 312 that is used, less energy is required to produce the required magnetic flux and less heat builds-up in the coil (this heat must be dissipated to ensure consistent operation of the injector). Yet another advantage is that the modular construction enables the orifice disk 254 to be attached at a later stage in the assembly process, even as the final step of the assembly process. This just-in-time assembly of the orifice disk 254 allows the selection of extended valve bodies depending on the operating requirement. Further advantages of the modular assembly include out-sourcing construction of the power group subassembly 300, which does not need to occur in a clean room environment. And even if the power group subassembly 300 is not out-sourced, the cost of providing additional clean room space is reduced.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations, and changes to the described

embodiments are possible without departing from the sphere and scope of the present invention, as defined in the appended claims. Accordingly, it is intended that the present invention not be limited to the described embodiments, but that it have the full scope defined by the language of the following claims, and equivalents thereof.